Analyzing Safety in Collaborative Cyber-Physical Systems: A Platooning Case Study

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Research Interests:

- Software engineering
- Deep learning,
- Cyber-physical systems
- Autonomous system’s safety.
- Deep reinforcement learning

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Research Interest: *software requirements engineering, data mining, ontology, software architecture, software process improvement, DevOps, software quality, system safety, system of systems, and cyber-physical systems.*

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Research Interests*: Cyber Physical Systems, safety, Simulation, autonomous vehicle, and Platoon driving.*

Topics to be discussed

1. Introduction
2. Motivation
3. Related Work
4. Proposed Approach
5. FPTG, FPG, and FBTG
6. Safety Verification
6. Conclusion

Introduction

- Collaborative Cyber-Physical Systems (CCPS)
  - Controlled, reliable, connected and complex system
  - Collaborate
  - Can perform complex task
- Cyber Physical Systems may face unexpected behavior
  - Unintended behavior of failure free system due to performance limitation
  - Lack of robustness
    - Environmental variabilities
  - Lack of composite hazard analysis
    - Lack of fault traceability
  - Insufficient situational awareness
- Single CPS's safety can be insured by
  - ISO 26262
  - IEC61508

Introduction

- Safety of CCPS becomes challenging tasks
  - Complex, diverse, variable and uncertain operational environment
    - e.g., autonomous platooning system
      - Environmental uncertainties such Fog, rain and snow
      - Infrastructural uncertainties such as black ice on road etc.
  - CCPS are massively interconnected
    - Single fault can activate many other fault in other collaborating systems.
- We present an enhanced fault traceability approach
  - Composite hazard analysis
  - Content relationship among hazard analysis artifacts
    - Fault Tree Analysis (FTA), Failure Mode and Effect Analysis(FMEA) and Event Tree Analysis (ETA)
  - Fault traceability Graphs
    - Fault Traceability and Propagation Graph (FPTG)
    - Fault Propagation Graph (FPG)
    - Fault Back Traceability Graph (FBTG)
  - Case Study: Autonomous Platooning System

Motivation

Introducing the enhanced fault traceability techniques

- Traceability Graphs
  - Single hazard analysis technique is not sufficient for CCPS
  - Composite hazard Analysis of CCPSs
  - Content relationships among hazard analysis artifacts
  - FPTG, FPG, FBTG
    - Fault Route
    - Source of Fault
    - Propagation Scope
    - Impact of fault of on other system
    - Safety guard
- Safety verification of Platooning systems
  - VENTOS Simulator
  - Hazardous scenarios *i.e., fog, rain, and black snow*

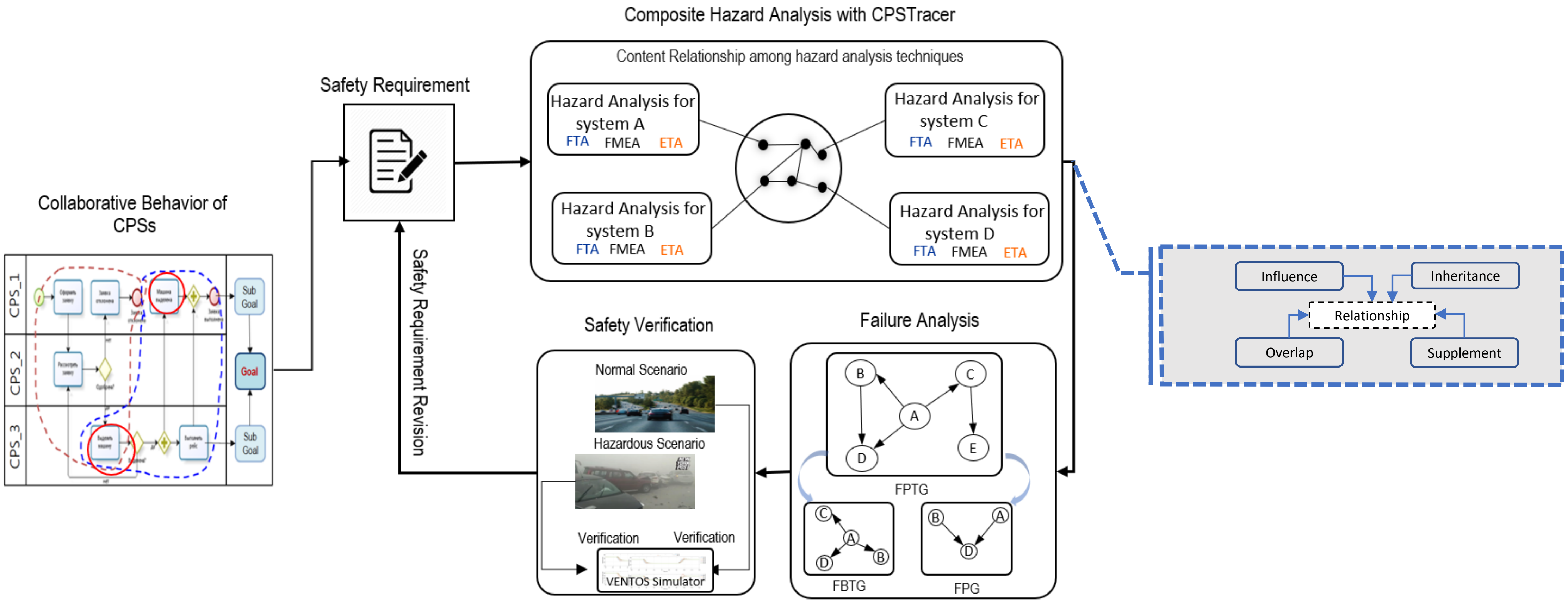
Composite Hazard Analysis

- **Composite Hazard Analysis Technique**
  - **FTA**
  - **FMEA**
  - **ETA**
- **Content Relationships**
  - **Influence Relationship**
  - **Inheritance Relationship**
  - **Overlap Relationship**
  - **Supplement Relationship**

Related Work

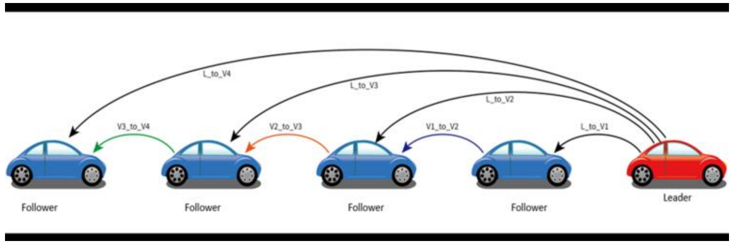
- Ali at el. Presents an approach that can model the uncertainties that a collaborative CPSs may face during their operation. They extended the traditional FTA, FMEA, ETA to model the variabilities and uncertainties in CPSs. [2020]
- Daneth et al. A domain-specific language (CyPhyML+) was to identify the interaction component and their uncertainties in collaborative CPSs.[2019]
  - The primary objective of this approach was to present the safety component and identifying unknown component interaction in CPSs ensuring safety
- Naufal et al. proposed a conceptual framework called A2CPS (autonomous CPSs) aiming to design and implement an autonomous supervision and control system. [2018]
  - Purpose of this approach was to reduce vehicle collision with resilient safety measure at run time
- Medawar et al. discussed the role of the run-time manager in SafeCOP to ensure continuous safety in truck platooning. [2017]
  - The authors first specify the safety contracts based on the safety analysis of the local system as well as the cooperative safety function.
- Zhang et al. proposed a taxonomy that can be translated under the uncertainty of the predictive model. [2016]
  - A self-healing model is proposed to ensure the sustainable safety of the CPSs.

Proposed Approach



Safety Analysis of Platooning System (A collaborative CPS)

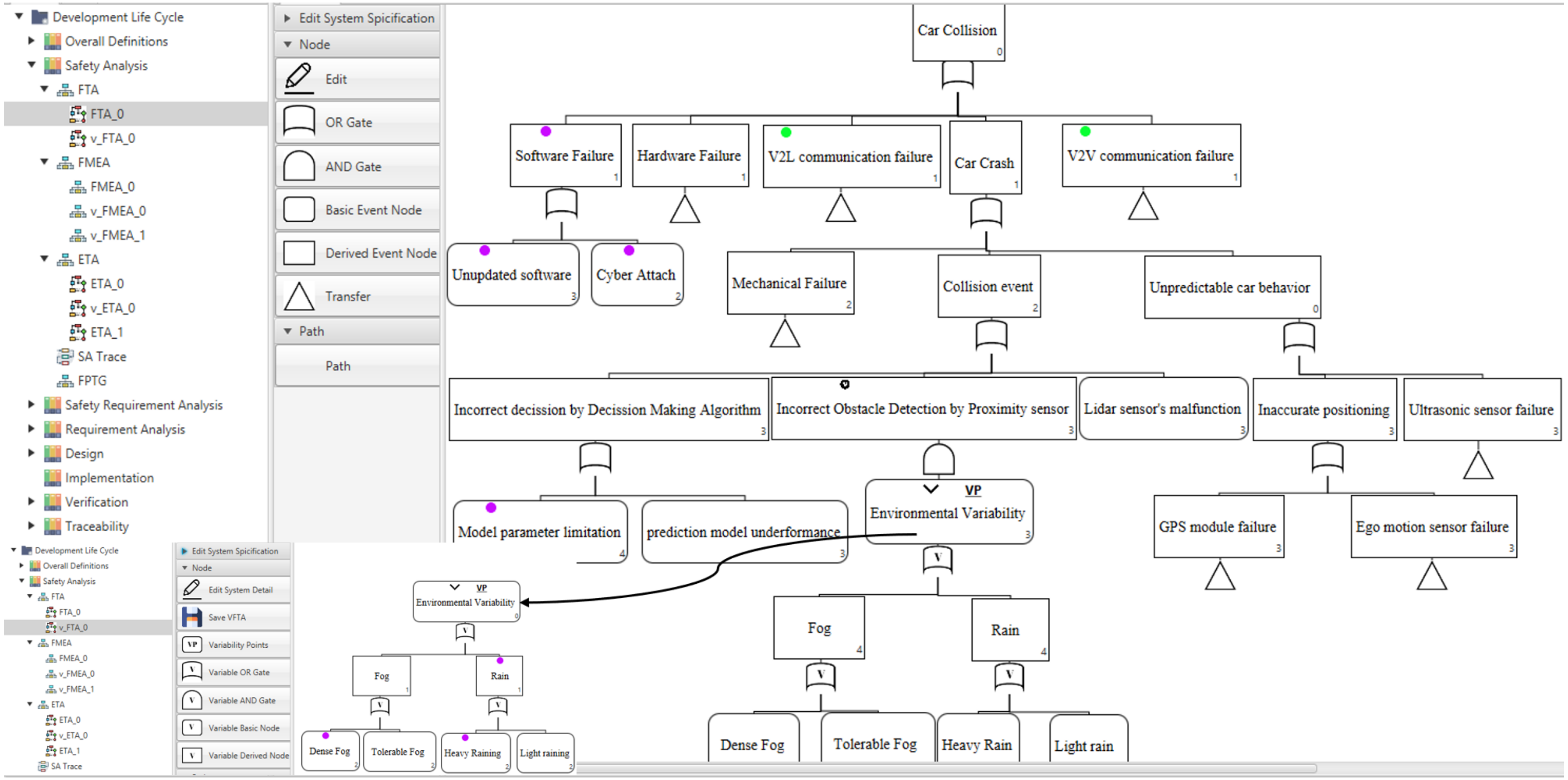
- Platooning System
  - The movement of vehicle group collaborates to reduce the inter-vehicle distance and creates synergy. The front vehicle called leader, and the following car called follower.
    - Better usage of road infrastructure i.e., can fit more vehicles on the road
    - Improve energy efficiency by reducing the aerodynamic drag
    - Reduce emission
    - Full consumptions



Example of Platooning system

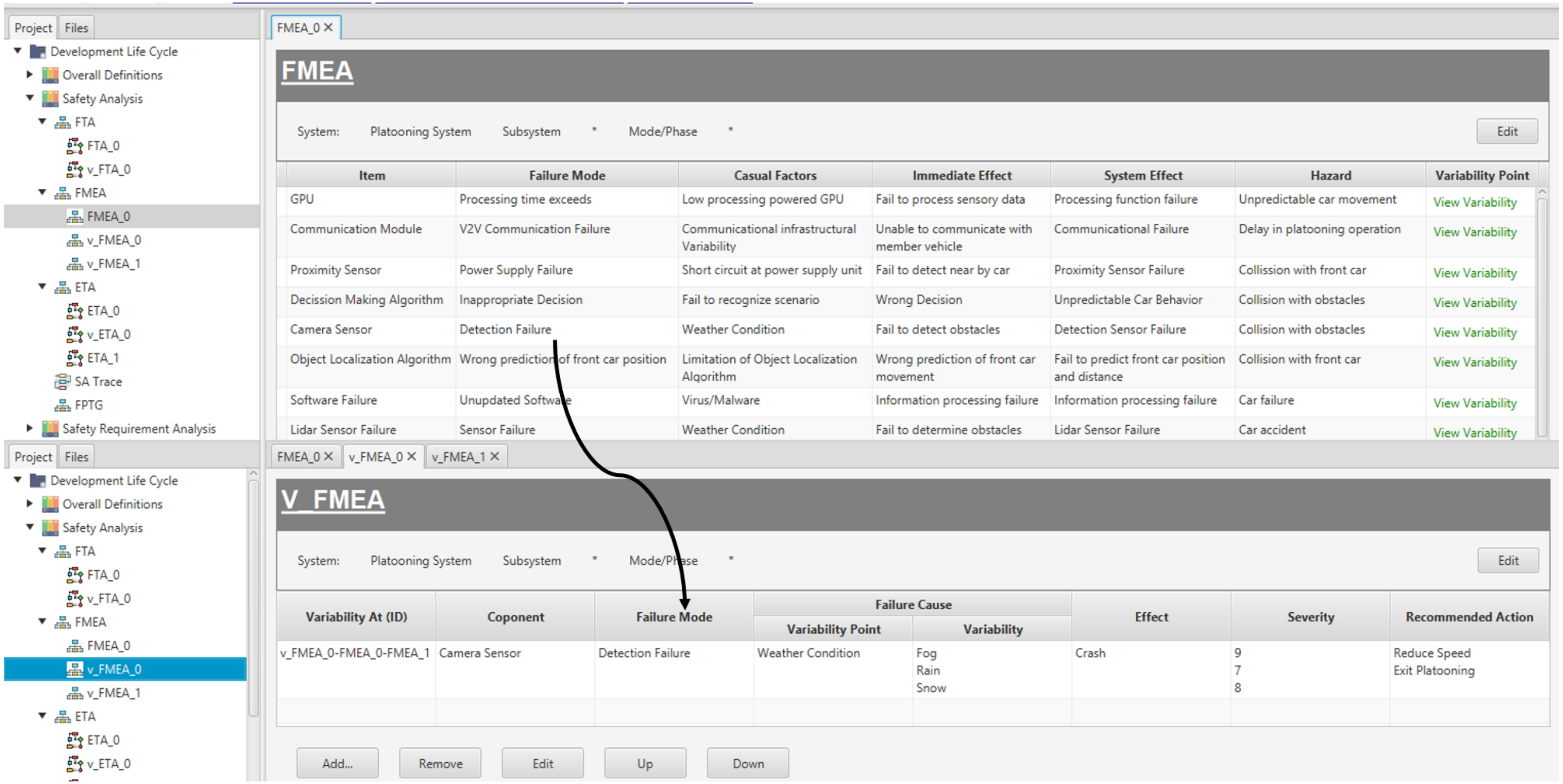
- However,
  - Reducing the inter-vehicle distance also leads to creating safety concerns in vehicles participating in the platooning.
  - The safety of collaborative CPSs can be ensured by analyzing the safety of the system considering the potential uncertainties.
    - To identify the potential hazards, analyze the faults, and measurement of possible damage.

Composite Hazard Analysis of Platooning CPS-Fault Tree Analysis



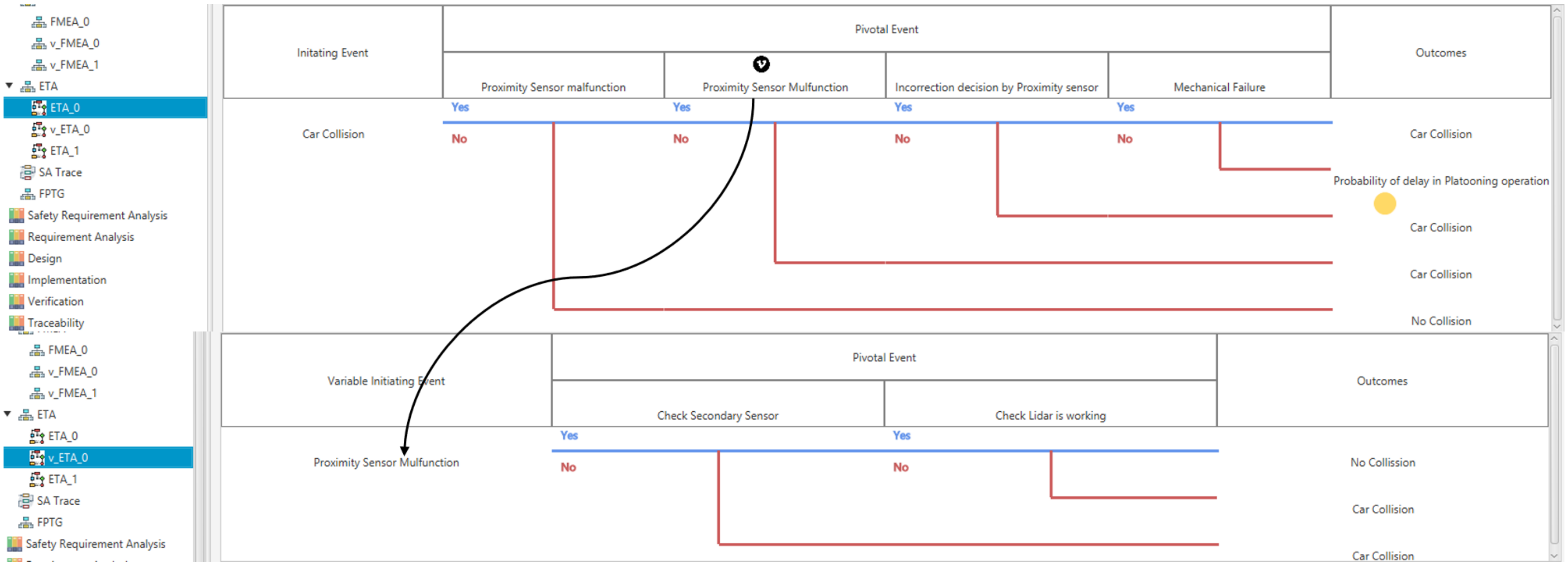
Fault Tree Analysis of The Platooning Systems

Composite Hazard Analysis of Platooning CPS- Failure Mode Effect Analysis



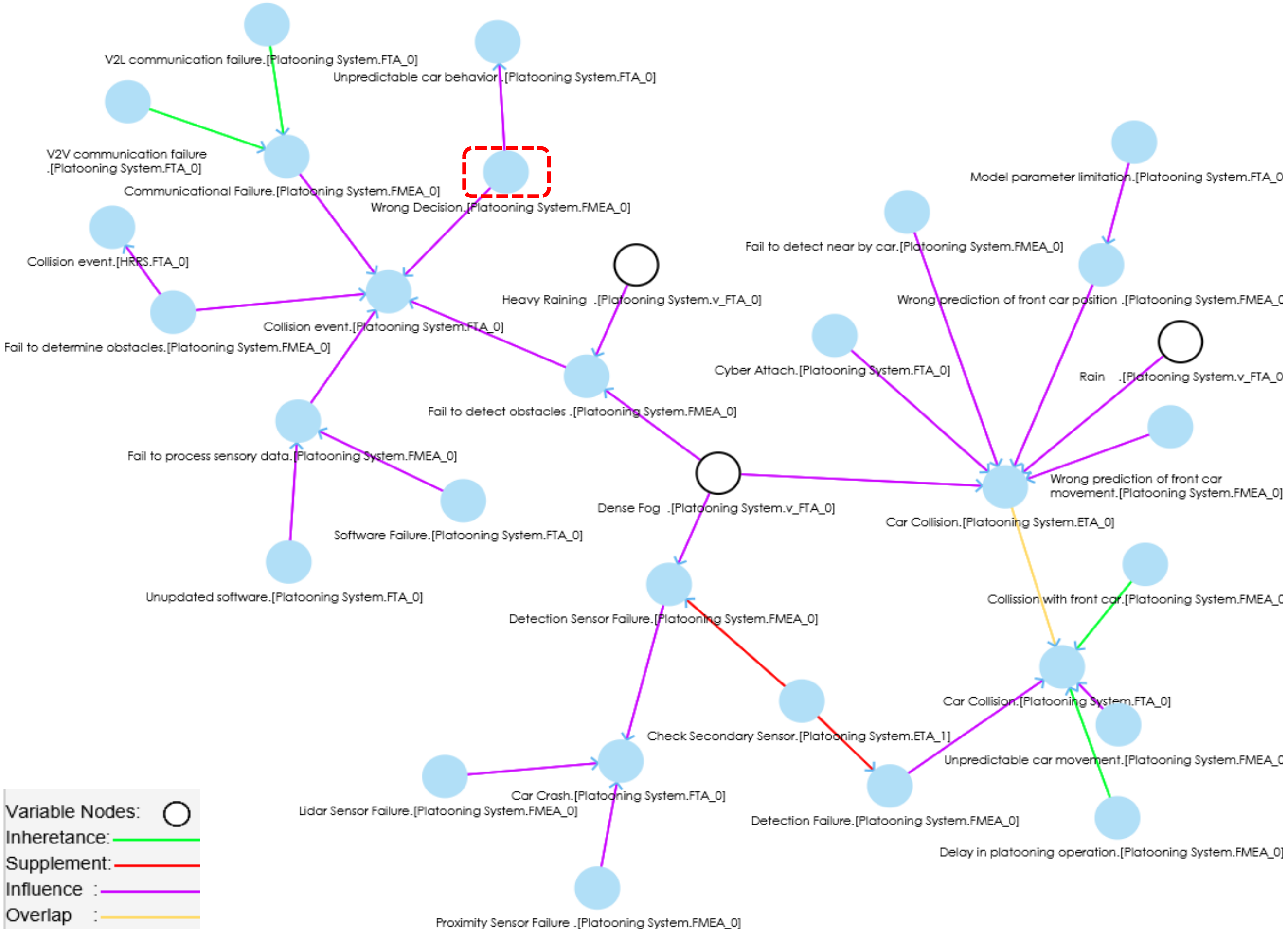
Failure Mode Effect Analysis of The Platooning Systems

Composite Hazard Analysis of Platooning CPS- Failure Mode Effect Analysis



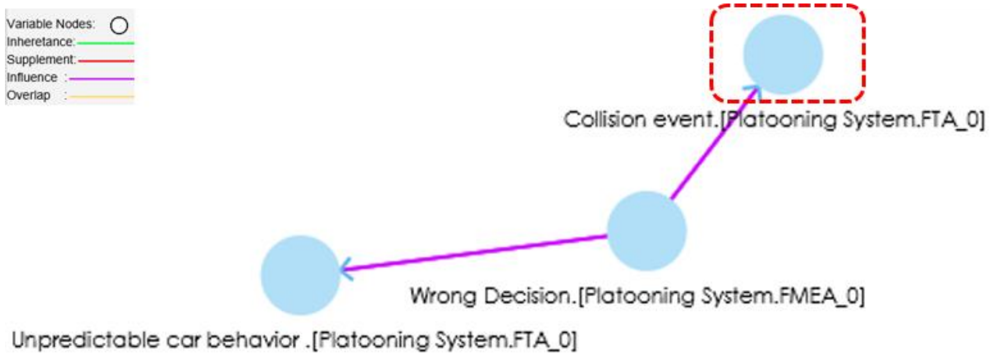
Event Tree Analysis of The Platooning System

Safety Analysis of Platooning System with FPTG

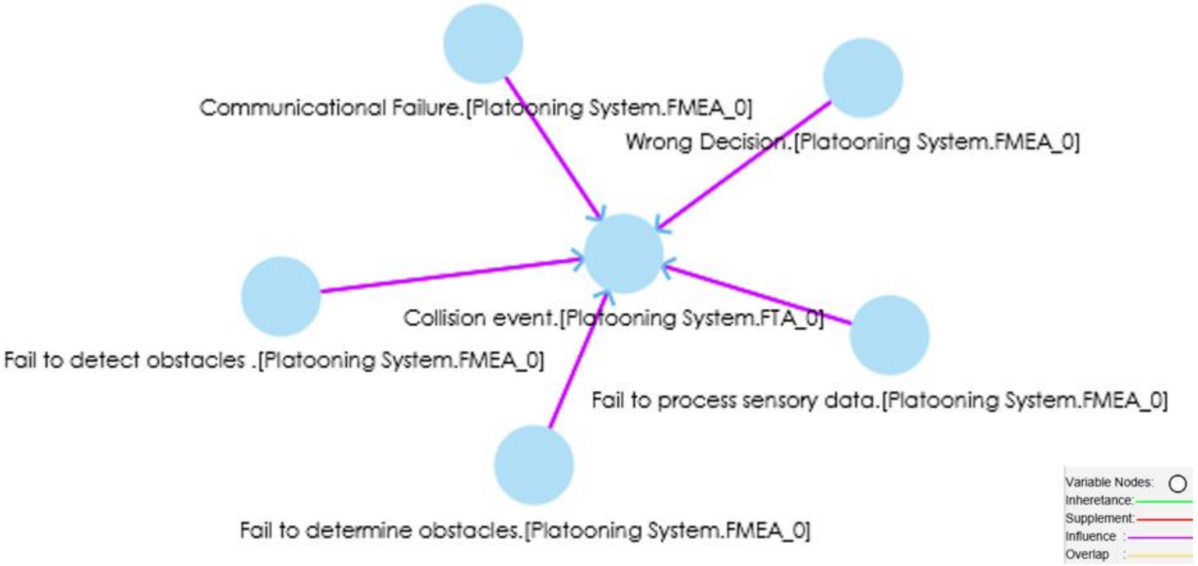


Fault Propagation Traceability Graph of the Platooning Systems

Safety Analysis of Platooning System with FPG and FBTG

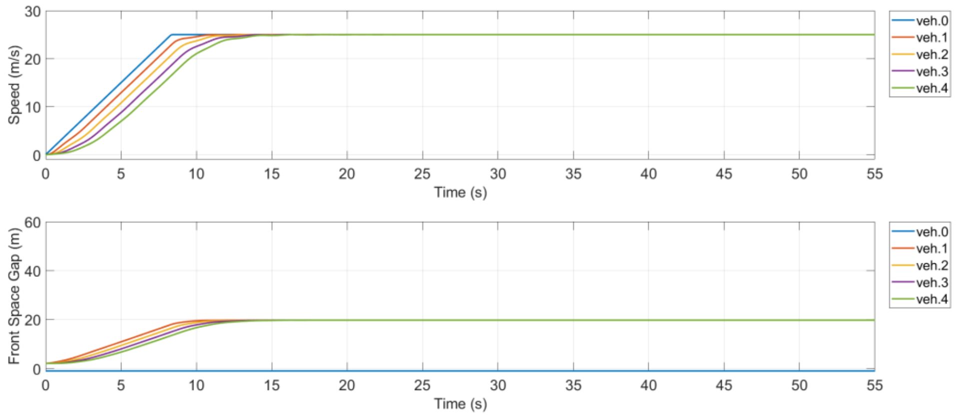


Fault Propagation Graph of the Platooning Systems

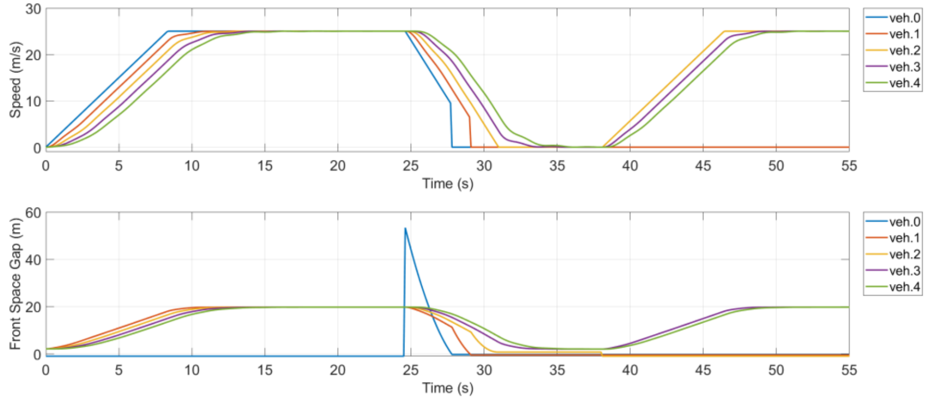


Fault Back Traceability Graph of the Platooning Systems

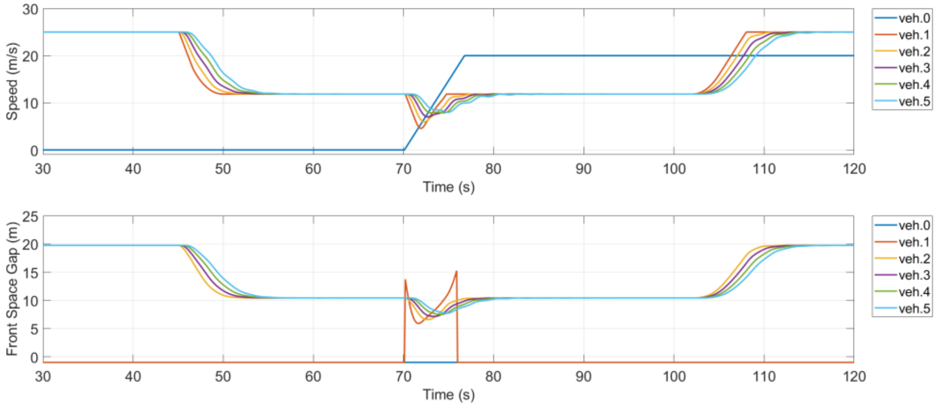
Safety Verification



Speed and inter-vehicle distance for the normal scenario.



Speed and inter-vehicle distance for the hazardous scenario.



Speed and inter-vehicle distance for safe scenario

Conclusion

- Collaborative Cyber-Physical Systems (CCPS)
  - Complex and massively in inter-connected
  - Unexpected behavior in CCPSs may comes due to diverse, variable and uncertain operational environment
- Safety of CCPS is challenging task due to
  - Complex, diverse, variable and uncertain operational environment
    - Environmental uncertainties such Fog, rain and snow
    - Infrastructural uncertainties such as black ice on road etc.
  - CCPS are massively interconnected
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  - Fault traceability Graphs
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    - Fault Back Traceability Graph (FBTG)
  - We verified our approach by analyzing the Autonomous Platooning System in VENTOS Simulations

Questions and Discusion

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